

DOCUMENT RESUME

ED 477 069

IR 021 797

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TITLE Pedagogical Agents in Virtual Reality Environments: Do
Multimedia Principles Still Apply?
PUB DATE 2002-06-00
NOTE 7p.; In: ED-MEDIA 2002 World Conference on Educational
Multimedia, Hypermedia & Telecommunications. Proceedings
(14th, Denver, Colorado, June 24-29, 2002); see IR 021 687.
AVAILABLE FROM Association for the Advancement of Computing in Education
(AACE), P.O. Box 3728, Norfolk, VA 23514. Tel: 757-623-7588;
e-mail: info@aace.org; Web site: <http://www.aace.org/DL/>.
PUB TYPE Reports - Evaluative (142) -- Speeches/Meeting Papers (150)
EDRS PRICE EDRS Price MF01/PC01 Plus Postage.
DESCRIPTORS Comparative Analysis; *Computer Games; *Educational Games;
Educational Media; Electronic Text; Instructional Design;
Learning Strategies; Multimedia Materials; Science Education;
Teaching Methods; *Virtual Reality

ABSTRACT

This paper reviews a set of studies that examined what students learn in various virtual reality environments (VREs) designed to promote an understanding of environmental science. The goal of the reported studies was to provide an update to the classic distinction between the role of media versus method in promoting learning (Clark, 1999). Media was varied by comparing how students learn from an instructional game delivered via a desktop display (D), head mounted display without walking (H), and head mounted display with walking (W). The instructional method was varied by comparing how students learn when words are presented as on-screen text (T), narration (N), or both (NT). (Contains 20 references.) (Author)

Pedagogical Agents in Virtual Reality Environments:

Do Multimedia Principles Still Apply?

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Abstract: In this paper, I review a set of studies that examined what students learn in various virtual reality environments (VREs) designed to promote an understanding of environmental science. The goal of the reported studies was to provide an update to the classic distinction between the role of media versus method in promoting learning (Clark, 1999). Media was varied by comparing how students learn from an instructional game delivered via a desktop display (D), head mounted display without walking (H), and head mounted display with walking (W). The instructional method was varied by comparing how students learn when words are presented as on-screen text (T), narration (N), or both (NT).

The Role of Media in Virtual Reality Environments

The first goal of this research was to examine the role of media in VREs. Thus, an important research issue concerns whether more immersive VREs (e.g., via head mounted displays) result in qualitatively different learning outcomes than less immersive VREs (e.g., via desktop computer displays). Immersion is defined as the extent to which computer displays are capable of delivering an inclusive, extensive, surrounding, and vivid illusion of reality to the senses of a human participant (Slater & Wilbur, 1997). How does immersion affect learning?

First, higher levels of immersion may promote a higher sense of presence which in turn, may promote more engagement and deeper learning. Presence is a subjective state, the psychological sense of being in a VRE (Slater & Wilbur, 1997). Past research in VREs, found that higher levels of immersion in the learning environment induce a higher sense of presence during the learning experience as measured by participants' ratings on a presence questionnaire (Welch et al., 1996). The fundamental idea is that a higher sense of being in the environment may encourage the deep processing of the learning task by engaging students in an active search for meaning (Moreno & Mayer, 2000).

Second, more immersive VREs may improve transfer of learning to the real world because the more similar a learning environment is to a real environment, the better the transfer of learning (Durlach & Mavor, 1995). Preliminary evidence supports the idea that the richer the perceptual cues and multimodal feedback (e.g., visual, auditory, haptic, etc.) the more likely the transfer of VR training to real-world skill (Regian, Shebilske, & Monk, 1992). This idea is also consistent with one of the grand aims of VREs for learning: to provide interface transparency by making the interaction with technology more "natural". The cognitive advantage of a transparent interface, which is generally concomitant with a more immersive environment, is that it drives students' limited attentional resources to learning the content material rather than to the interface.

The Role of Method in Virtual Reality Environments

The second goal of this research was to examine the role of method in VREs. Method refers to the instructional method implemented in the design. For the case of the reported studies, the role of the modality of the verbal information was examined. More specifically, the instructional method was varied by presenting the words printed

as on-screen text (T), spoken as narration (N), or both (NT). How does the modality of the verbal information affect learning? To answer this question, I start with a dual-processing theory of multimedia learning.

According to dual-processing theory, students who can hold corresponding pictorial and verbal representations in working memory at the same time (such as the dynamic graphics of the VREs held in visual working memory and the corresponding narrated explanations held in auditory working memory) are better able to build referential connections between them (Paivio, 1986). On the other hand, given the limited resources students have for visual working memory, using a visual modality to present both pictorial and verbal information can create an overload situation for the learner (Baddeley, 1992; Chandler & Sweller, 1991; Sweller, 1989). Previous research in a desktop environment has shown that students learn better--as measured by tests of retention and transfer--when the instructional method involves spoken rather than printed explanations (Mayer & Moreno, 1998; Moreno & Mayer, 1999; Moreno & Mayer, 2002; Moreno, Mayer, Spires, & Lester, 2001). Similar results were obtained in an immersive VR training environment (O'Neil et al., 2000). This effect of instructional method has been called the modality effect (Moreno & Mayer, 1999; Moreno et al., 2001).

Does redundant verbal information (identical narration and on-screen text presented simultaneously) facilitate students' understanding of an interactive VR program further? Recent findings on learning with short multimedia explanations have shown that when instructional materials contain simultaneous pictorial information such as animations, adding identical on-screen text to a spoken explanation hurts rather than helps students' learning (Mayer, Heiser, & Lonn, 2001; Moreno & Mayer, 2002). The negative effects of redundant verbal messages have been interpreted as due to learners' need to split their limited visual attention between simultaneous text and graphics. This effect of instructional method has been called the redundancy effect.

Media Versus Method

The decision to use different delivery media (D, H, or W) or methods (N, T, or NT) in instructional design may depend on one's conception of learning. In this section, I consider the following two views: media-affects learning and method-affects-learning.

Media-Affects-Learning

On one hand, a media-affects-learning view is that the delivery medium can affect what is learned. Media refers to the delivery device; in this case I varied the degree of immersion by presenting the instructional program via a desktop computer screen (D), via a head mounted display while the learner is seated (H), or via a head mounted display while the learner can walk (W). For example, Seidel and Chatelier (1997, p. 2) call for research comparing how people learn from desktop workstations versus from head mounted displays (HMDs) by asking, "What is the value added by HMD, and what purposes or what types of tasks does it serve best for learning purposes?"

According to the media-affects-learning view, immersive VREs (such as in conditions W and H) have the potential of making computer-based learning feel more real by promoting a sense of presence, which in turn, could promote deeper learning. The effect of media would be reflected in superior performance on tests of retention and transfer for students who experience more immersive environments. If media affects learning, then a media effect would be expected, that is, performance on tests of retention and transfer depends on whether the instructional program was presented by desktop display, head mounted display, or head mounted display with walking. This pattern would be reflected in a main effect for media and no interaction between method and media.

Method-Affects-Learning

On the other hand, the method-affects-learning view is that instructional methods influence learning. Instructional methods can guide cognitive processing in the learner, which influences the knowledge that the learner is able to construct. According to the method-affects-learning view, it is not technology per se that promotes learning but rather how the technology is used. As long as instructional methods promote appropriate cognitive processing during learning, then media does not seem to matter (Clark, 1999). Although VR offers a compelling technological breakthrough, the medium itself does not promote learning but rather the instructional methods that it affords promote learning.

In the present review, the modality of the verbal information was used as instructional method. Therefore, the effect of method would be reflected in two ways. First, by demonstrating a modality effect, that is, superior performance on tests of retention and transfer for students who receive verbal explanations as narration (N) rather

than as on-screen text (T). Second, by demonstrating a redundancy effect. Students who receive verbal explanations as narration (N) will outperform those who receive redundant explanations (NT) on tests of retention and transfer.

The main interest of the reported studies is the general issue of whether method affects learning across media--that is, whether instructional methods have the same effects within different media environments. If method affects learning, then a modality or redundancy effect can be expected within each of the VREs examined--desktop display, head-mounted display, and head mounted display with walking. This pattern would be reflected in a main effect for method and a lack of interaction between method and media.

A Virtual Reality Agent-Based Micorworld

The learning environment used in the reported studies is a computer game called "Design-A-Plant", developed by the Multimedia Laboratory at the Department of Computer Science of North Carolina State University (Lester & Stone 1997). In this program, the student travels to an alien planet that has certain environmental conditions (e.g., low rainfall, light sunlight) and must design a plant that would flourish there (e.g., including designing the characteristics of the leaves, stem, and roots). It includes a pedagogic agent who offers individualized advice concerning the relation between plant features and environmental features, encouragement when students encounter difficulties, and feedback on the choices that students make in the process of designing plants. The program starts with the agent introducing the student to the first set of environmental conditions. Then, he asks the student to choose the appropriate root from the library of roots' names and graphics shown on the computer screen. After the student had chosen a root, the agent gives a narrated explanation for the correct root. The same procedure applies to the stem and leaves, with the agent first asking the student to make a choice, and giving the student feedback afterwards. Once the student is given the last explanation on the leaves for each environment, he is taken to the next environment. The same procedure follows for the rest of the environments.

Experiment 1: Media Versus Modality Effects

Method and Results

The participants were 89 college students. Each participant served in one cell of a 2 x 3 between-subjects factorial design, with the first factor being modality of the verbal information (narration or text) and the second factor being the level of immersion during the computer interaction (desktop, head mounted display, or head mounted display plus walking). There were 17 participants in the narration and desktop group (ND Group), 17 participants in the text and desktop group (TD Group), 13 participants in the narration and head mounted display group (NH Group), 13 participants in the text and head mounted display group (TH Group), 13 participants in the narration and head mounted display plus walking group (NW Group), and 14 participants in the text and head mounted display plus walking group (TW Group).

After interacting with the respective program, participants were tested on three important measures of learning: retention--in which memory for the basic factual information was assessed; problem-solving transfer--in which students were asked to solve new problems based on the principles learned in the program; and program ratings--in which students were asked to rate their level of motivation, interest, understanding, and the perceived difficulty and friendliness of the lesson. Participants also completed a presence questionnaire. We determined whether the groups differed on measures of retention, transfer, and program ratings by conducting two-factor analyses of variance for each dependent measure with modality (T or N) and level of immersion (D, H, or W) as between-subject factors, and retention, transfer, and program ratings as the respective dependent measure.

Do students experience a stronger sense of presence in more immersive VREs?

Consistent with past research in VREs, higher levels of immersion in the learning environment induced a higher sense of presence during the learning experience (Welch et al., 1996). Using presence as a dependent measure, a one-factor ANOVA revealed that students in D groups rated their sense of presence significantly lower than students in H and W groups which did not differ from each other, $M_s = -2.59, 7.31, \text{ and } 8.22$; $SD_s = 12.49, 10.03, \text{ and } 12.33$, for D, H, and W groups, respectively, $p = .0006$.

Do more immersive VREs promote deeper learning than less immersive VREs?

The media-affects-learning view holds that more immersive VREs are more likely to promote students' learning of the science lesson, by virtue of inducing higher levels of presence. Using retention as a dependent measure, a two-factor ANOVA failed to reveal a main effect for immersion. Groups presented with higher levels of immersion did not differ in the mean number of recalled items about the plant library from those presented with lower levels of immersion ($M_s = 6.01, 6.50, \text{ and } 5.82$; $SD_s = 1.85, 1.85, \text{ and } 2.04$, for D, H, and W groups, respectively). There was no significant interaction between immersion and modality.

Using transfer as a dependent measure, a two-factor ANOVA failed to reveal a main effect for immersion. Groups presented with higher levels of immersion did not differ in the mean number of answers from those presented with lower levels of immersion ($M_s = 31.06, 30.69, \text{ and } 30.52$; $SD_s = 9.54, 9.20, \text{ and } 11.68$, for the D, H, and W groups, respectively). A significant interaction was found between immersion and modality ($p < 0.05$). Post hoc analysis of simple effects for modality and immersion indicated that both for D and H conditions, receiving information via on-screen text rather than via narration, proved to significantly hinder students' learning as measured by transfer scores ($p = .006 \text{ and } .0001$, respectively). Similar to the case for retention, there was no immersion effect for students' program ratings and no interaction. The respective ratings for the D, H, and W groups were: $M_s = 28.67, 31.83, \text{ and } 31.52$, $SD = 6.61, 7.02, \text{ and } 6.88$.

Do students who learn with narration learn more deeply than students who learn by reading on-screen text?

The method-affects-learning view holds that presenting verbal material as speech is more likely to promote students' understanding of a multimedia lesson than presenting the same material as on-screen text, regardless of delivery medium. Using retention as a dependent measure, a two-factor ANOVA revealed a main effect for modality ($p = .0003$), with a mean number of ideas recalled of 6.84 and 5.43 respectively for the narration and text groups ($SD_s = 1.51 \text{ and } 2.01$, respectively).

Using transfer as a dependent measure, a two-factor ANOVA revealed a main effect for modality ($p = .0001$), with a mean number of correct answers of 36.12 and 25.57 respectively for the narration and text groups ($SD_s = 8.34 \text{ and } 8.80$, respectively). Groups presented with the verbal information in the form of speech gave significantly more correct answers than those presented with the verbal information in the form of text. Groups also differed in the overall ratings for the program. A two-way ANOVA using program ratings as the dependent measure revealed that the narration groups rated the program more favorably than the text groups ($p < .05$), with a mean rating of 32.33 and 28.72 respectively for the narration and text groups ($SD_s = 5.85 \text{ and } 7.42$, respectively).

The results from Experiment 1 supported the method-affects-learning hypothesis by demonstrating a modality effect on retention, problem-solving transfer, and program ratings. No evidence was found in favor of the media-affects-learning hypothesis. The purpose of Experiment 2 was to test the alternative hypothesis using a different type of instructional method. The effects of presenting redundant verbal information by means of a VR desktop display (D) or by means of a head mounted display without walking (H) was examined. Students received explanations from an agent via narration alone (N), via on-screen text alone (T), or via simultaneous narration and on-screen text explanations (NT).

Experiment 2: Media Versus Redundancy Effects

Method and Results

The participants were 75 college students. Each participant served in one cell of a 3×2 between-subjects factorial design, with the first factor being modality of the verbal information (narration, text, or narration and text) and the second factor being the level of immersion during the computer interaction (desktop or head mounted display). There were 14 participants in the narration and desktop group (ND Group), 14 participants in the text and desktop group (TD Group), 14 participants in the redundant desktop group (NTD Group), 11 participants in the text and head mounted display group (TH Group), 10 participants in the narration and head mounted display group (NH Group), and 12 participants in the redundant head mounted display group (NTH Group). The procedure was identical to that of the first experiment. To determine whether treatment groups differed on measures of retention, transfer, and program ratings, separate two-factor analyses of variance were conducted for each dependent measure with modality (N, T or NT) and level of immersion (D or H) as between-subject factors, and retention, transfer, and program ratings as the respective dependent measure.

Do students experience a stronger sense of presence in more immersive VREs?

Similar to Experiment 1, the results showed that programs delivered via head-mounted displays rather than desktop displays induce higher levels of presence ($p = .03$). Students in the D groups rated their sense of presence significantly lower than students in the H groups. ($M_s = .81$ and 8.73 ; $SD_s = 12.95$ and 17.93 , for D and H groups, respectively).

Do more immersive VREs promote deeper learning than less immersive VREs?

Using retention as a dependent measure, a two-factor ANOVA failed to reveal a main effect for immersion or an interaction between immersion and modality. Groups who learned in the desktop conditions did not differ in the mean number of recalled items about the plant library from groups who learned with higher levels of immersion ($M_s = 6.81$, and 6.55 ; $SD_s = 1.55$ and 1.68 , for D and H groups, respectively).

Using transfer as a dependent measure, a two-factor ANOVA failed to reveal a main effect for immersion or an interaction between immersion and modality. Groups presented with higher levels of immersion did not differ in the mean number of answers from groups presented with lower levels of immersion ($M_s = 28.17$, and 30.55 ; $SD_s = 7.47$ and 7.36 , for the D and H groups, respectively). Similarly, a two-way ANOVA using the overall program rating as the dependent measure failed to reveal an immersion effect. The respective ratings for the D and H groups were: $M_s = 30.14$ and 28.49 , $SD = 6.95$ and 7.02 . There was no significant interaction between immersion and modality.

Do students who learn with redundant explanations learn more deeply than students who learn with explanations in only one modality?

The method-affects-learning view holds that presenting verbal material as narration alone is more likely to promote students' understanding of a multimedia lesson than presenting the same verbal material as narration and on-screen text, regardless of delivery medium. Using retention as a dependent measure, a two-factor ANOVA revealed a main effect for modality ($p = .006$), with a mean number of ideas recalled of 7.25 , 6.96 , and 5.88 respectively for the N, NT, and T groups ($SD_s = 1.57$, 1.46 , and 1.51 , respectively). Supplemental Tukey tests (with alpha at $.05$) revealed that groups presented with on-screen text alone recalled significantly fewer items from the plant library than groups presented with narration alone or with narration plus on-screen text, which did not differ from each other.

Using transfer as a dependent measure, a two-factor ANOVA revealed a main effect for modality ($p = .0004$), with a mean number of correct answers of 32.08 , 30.77 , and 24.84 , respectively for the N, NT, and T groups ($SD_s = 6.16$, 8.15 , and 5.96 , respectively). Similar to the case of retention, supplemental Tukey tests (with alpha at $.05$) revealed that groups presented with on-screen text alone gave significantly less correct answers to problem-solving transfer tests than groups presented with narration alone or with narration plus on-screen text, which did not differ from each other. Groups also differed in the overall ratings for the program ($p = .01$), with a mean rating of 32.54 , 29.31 , and 26.52 respectively for the N, NT, and T groups ($SD_s = 5.36$, 6.87 , and 7.43 , respectively). Supplemental Tukey tests (with alpha at $.05$) revealed that groups presented with on-screen text alone gave significantly lower program ratings than students presented with narration alone.

Overall, modality effects were obtained on the retention, transfer, and program ratings replicating the pattern found in Experiment 1 and thus supporting the method-affects-learning hypothesis. However, redundant verbal information did not hurt or help students' understanding as compared to spoken explanations alone. A possible interpretation for NT groups performing comparably to N groups is that students in NT groups may have been inclined to attend to the narration alone due to the experiential mode of VREs. When students are exploring a VRE (either by moving the computer mouse or by moving their head), it is less likely that they will read a box containing text if they can obtain the same information by listening to a narration.

General Discussion

The present review yields evidence--based on questionnaires--that students feel a stronger sense of presence in more immersive VREs. In addition, the reported studies provide new evidence--from retention and transfer tests--that students who experience more immersive VREs do not necessarily learn a computer-based lesson more deeply than students who experience a lower sense of presence. This is consistent with past research in VREs where no

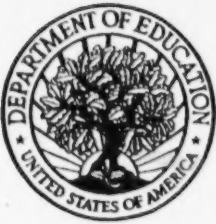
relationship between presence and performance was found (Slater & Wilbur, 1997) and fails to support a media-affects-learning hypothesis.

Theoretically, this research provides one of the first methodologically rigorous studies of conditions that foster productive learning in a virtual environment. The replication of the modality effect across different media shows that effective learning depends on which instructional techniques help guide the learner's cognitive processing of the presented material rather than on the medium per se. Importantly, this review has shown that the same factors that improve student understanding in one medium (such as modality effects in a desktop environment) improve student understanding in another medium (such as the present findings concerning immersive VREs). In both cases, ineffective instructional messages can be converted into effective ones by applying the same instructional design principles.

Finally, the conclusions drawn are limited by the nature of the learning materials. The learning materials consisted of an environmental science VRE with short agent and student interventions. It is possible that in VREs where students' physical interventions are essential to the learning process, such as if the goal of the instructional material is to train a procedure, the use of more immersive environments might play an important role in adding psychomotor feedback to the learning experience (Seidel & Chatelier, 1997; Thurman & Russo, 2000). Because some media may enable instructional methods that are not possible with other media, it might be useful to explore instructional methods that are possible in immersive environments but not in others.

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